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Quarterly Technical Summary

General Research

15 February 1970

Prepared under Electronic Systems Division Contract AF 19(628)-5167 by

Lincoln Laboratory
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Lexington, Massachusetts

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INTRODUCTION

This Quarterly Technical Summary covers the period from 1 November 1969 through 31 January 1970. It consolidates the reports of Division 2 (Data Systems), Division 4 (Radar), Division 5 (Optics), Division 7 (Engineering), and Division 8 (Solid State) on the General Research Program at Lincoln Laboratory.

Accepted for the Air Force
Franklin C. Hudson
Chief, Lincoln Laboratory Office

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OPTICS – DIVISION 5

ENGINEERING – DIVISION 7

SOLID STATE – DIVISION 8

DATA SYSTEMS
DIVISION 2

INTRODUCTION

This section of the report reviews progress during the period 1 November 1969 through 31 January 1970 for the General Research Program of Division 2. Separate progress reports on Graphics and Seismic Discrimination describe other work in the Division.

M. A. Herlin
Acting Head, Division 2

DIVISION 2 REPORTS ON GENERAL RESEARCH

15 November 1969 through 15 February 1970

PUBLISHED REPORTS

Journal Articles*

JA No.			
3502	Seasonal Variation of the F1 Region Ion Composition	J. V. Evans L. P. Cox	J. Geophys. Res. 75, 159 (1970)
3519	Detection of Conjugate Photoelectrons at Millstone Hill	J. V. Evans I. J. Gastman†	J. Geophys. Res. 75, 807 (1970)
3560	Determination of F-Region Vertical Drifts at Millstone Hill	J. V. Evans R. A. Brockelman R. F. Julian W. A. Reid L. A. Carpenter†	Radio Sci. 5, 27 (1970)

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UNPUBLISHED REPORTS

Journal Articles

JA No.			
3440	Search for an Effect of the Sun on the Frequency of 18-cm Radiation	J. A. Ball D. F. Dickinson† A. E. Lilley† H. Penfield† I. I. Shapiro	Accepted by Science
3595	OH Radio Emission Associated with Infrared Stars	W. J. Wilson† A. H. Barrett† J. M. Moran	Accepted by Astrophys. J.
3599	Surface Height Variations of Venus and Mercury	W. B. Smith R. P. Ingalls I. I. Shapiro M. E. Ash	Accepted by Radio Sci.
3609	Remote Probing of the Moon by Infrared and Microwave Emission and by Radar	T. Hagfors	Accepted by Radio Sci.

* Reprints available.

† Author not at Lincoln Laboratory.

JA No.

3630	Detection and Estimation Practices in Radio and Radar Astronomy	T. Hagfors J.M. Moran	Accepted by Proc. IEEE
3632	Radar Measurements of Martian Surface Topography and Roughness	A.E.E. Rogers M.E. Ash C.C. Counselman G.H. Pettengill* I.I. Shapiro	Accepted by Radio Sci.

Meeting Speeches†

MS No.

2537B	Radar Studies of Planetary Surfaces	J.V. Evans	Conference on Planetary Atmosphere, Goddard Institute, 12-13 February 1970
2707	Long Baseline Interferometric Observations of the OH Source NML Cygnus	J.M. Moran A.H. Barrett* W.J. Wilson*	American Astronomical Society, Hayden Planetarium, New York, 8-11 December 1969
2736	Martian Topography and Surface Roughness from Radar Measurements at 3.8 cm	G.H. Pettengill* M.E. Ash C.C. Counselman* A.E.E. Rogers I.I. Shapiro	American Astronomical Society, San Francisco, 19-21 January 1970

* Author not at Lincoln Laboratory.

† Titles of Meeting Speeches are listed for information only. No copies are available for distribution.

SURVEILLANCE TECHNIQUES
GROUP 21

I. SUMMARY

Group 21 is responsible for the operation and the maintenance of the Millstone Radar and the Haystack Research facilities of Lincoln Laboratory's Millstone Hill Field Station. At Haystack, the emphasis is on planetary and lunar radar and on radiometric techniques, whereas at Millstone, ionospheric and radar propagation studies related to precision tracking techniques are conducted for the Advanced Ballistic Missile Defense Agency (ABMDA).

The NASA-requested Mars work has been completed and a final report has been published.* In the NASA lunar program, the radar maps have nearly all been developed from the past year's data and the final report is in preparation. Successful observing of Venus and Mercury continues to improve the knowledge of surface topography and orbital motions.

Of particular interest in radio astronomy were VLBI measurements at H_2O vapor wavelength (22.2 GHz) made jointly with NRAO and the NRL dish at Maryland Point. In cooperation with AFCRL, the first scientific use of Haystack at 35 GHz was also made in support of their solar research.

In January, Haystack officially began supporting observing programs of university scientists under the terms of a grant in support of radio astronomy awarded by the National Science Foundation to the Northeast Radio Observatory Corporation (NEROC). An agreement between NEROC and Lincoln Laboratory, defining administrative arrangements, has been drafted.

II. SPACE SURVEILLANCE TECHNIQUES

Two-frequency (i.e., 400 and 1295 MHz) passive tracking of two radio stars, Cas A and Cygnus, is producing data needed for antenna pointing calibration at both frequencies. From these data and the known ephemerides of these two radio sources, a seven-parameter function will be determined to correct for antenna imperfections associated with gravitational deformations and misalignments of the antenna axes. This program has also yielded interesting information on low-elevation scintillation.

The 84-foot tracking antenna is being used for passive tracking of UHF beacon satellites, with raw angle and doppler data being recorded on magnetic tape for later analysis of scintillation and other tracking perturbations attributable to ionospheric anomalies.

Smooth computer steering of the antenna on the basis of real-time orbit-fitting to currently stored smoothed observations is showing increased success as antenna calibrations proceed. This technique is expected to permit the measurement of tracking anomalies without contamination by the less well controlled antenna motions encountered when auto-tracking.

The above work as well as the continuing Thomson scatter ionospheric program are covered in the semiannual report to ABMDA.

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*Final Report, Radar Studies of Mars, Lincoln Laboratory, M.I.T. (15 January 1970).

III. HAYSTACK PLANETARY RADAR

A. Engineering

The dual-channel maser was removed from the receiver system in January in an attempt to improve the match of the input and output ports in order to widen the tuning range and to eliminate a bandpass drift problem that has seriously affected spectral line radiometry observations. The results of this work will be evaluated in February.

The radar receiver ran in January with the original Ser. No. 1 maser. System temperatures of 44°K at 45° elevation angle were achieved, essentially the same as with the best channel of the dual maser. This confirms the conjecture that the major improvement in system temperature achieved in late 1968 was due to improved waveguide arrangements.

Two VA-949AM transmitter klystrons were evaluated by high-power testing during this period. Serial No. 17 demonstrated DC arcing problems in the cathode region, and is being held only as a contingency backup. Serial No. 16, which had been rebuilt by Varian, was tested but was returned to the plant when an apparent vacuum leak was observed. Unfortunately, the klystron collector melted under high-power test at the plant, removing it from our limited inventory.

Serial No. 1 was reinstalled with Ser. No. 13 in the transmitter for all operations during this quarter. Unfortunately, Ser. No. 1 has developed a body current problem and the heater must be operated at a high level to sustain emission. This klystron has had over 3000 hours of heater operation and is approaching the end of its useful life. Transmitter power was limited to 300 kW, but fairly reliable operation was achieved for the important Venus conjunction period.

One new unit, Ser. No. 18, has been completed and tested as a single unit at the Varian plant and is scheduled to be delivered in February. This klystron must still be tested in parallel operation in the Haystack transmitter.

The most important improvement to the frequency and time standards was the installation of a rubidium vapor frequency standard to provide a backup for the hydrogen maser, which is itself undergoing modifications to reduce maintenance and improve reliability.

B. Planetary Studies

1. Mars

Further analysis of the partially NASA-supported radar measurements of Mars has provided new clues to the nature of the Martian surface. By correlating the radar results with optical observations, it is clear that the optically dark areas have a significantly higher intrinsic radar reflectivity and are somewhat smoother on the scale of the 3.8-cm radar wavelength than other regions. In the strip of the planet extending from the equator to 22°N, which has now been probed by radar, there seems to be a distinct tendency for dark areas to occur on the eastern slopes of the highlands. These results are consistent with the idea that dark areas may be bare rock having a high radar reflectivity, while other areas may be dust-covered surfaces of low radar reflectivity. The tendency of bare rock areas to be on the eastern slopes of Martian highlands might be due to a prevailing wind pattern in the equatorial zone.

Conclusions from the radar study that might be considered most important for the landing of a spacecraft on Mars are:

(a) Mean small scale surface slopes are sufficiently small that there is a high probability that a spacecraft would land on an area with a surface slope of only a few degrees.

(b) Comparison of the radar topography measurements with Mariner 6 data on surface pressure and scale heights shows that the surface pressure on Mars ranges from 3 millibars in highland regions to 9 millibars in the lowlands.

A final report on this project has been published.

2. Venus and Mercury

Ranging observations of the two inner planets continued during November and January for the Fourth Test of Relativity experiment. A superior conjunction of Mercury was observed in November 1969, but the major event was the superior conjunction of Venus about 23 January 1970. An extensive series of observations were made as the planet went within 1.2° of the sun. The signal-to-noise ratio achieved was sufficient for range measurement accuracies on the order of 10 μsec. Although an intermittent CDC 3300 computer problem developed during this period, which seriously degraded some of the observations, this superior conjunction observation may nonetheless be the best yet achieved.

C. Lunar Studies

With Air Force permission, the Lunar Studies program has been conducted with partial support from the NASA Manned Spacecraft Center, Houston, Texas.

The "polarized" (right circular transmitted; left circular received) radar backscatter maps have been assembled into five mosaics that comprise the entire earthside hemisphere. The mismatches that appeared in some of the overlapping areas of the ZAC* maps during assembly of the mosaics strongly suggest distortion of the maps by local lunar topography. This effect may be investigated further, although it is more likely that we will concentrate on our proposed direct study of topography with the use of the Hayford interferometer this spring.

The average scattering law for "depolarized" (right circular transmitted; right circular received) radiation has now been calculated and appears to agree extremely well with a cosine dependence on angle of incidence. However, a closer examination of the "polarized" return reveals that the scattering law indicated is in disagreement with the one previously found by J. V. Evans (and used in the mapping programs) in that the brightening at the center is about 3 dB less than Evans' law would show. This apparent disagreement is being studied.

We were invited by NASA to take part in the selection of future landing sites for Apollo missions 13 through 20. In late October, S. H. Zisk attended as consultant a meeting of the NASA Group for Lunar Exploration Planning (GLEP), at which time a list was made of primary and alternate landing sites which were chosen based on their scientific interest and variety and on their practical accessibility to the Apollo vehicles.

We were also asked by Dr. R. Petrone, Apollo Program Director, to join an ad hoc committee to study the problem of dust obscuration of the landing area during Apollo Landing Module descent, such as occurred rather frighteningly on Apollo 12. This committee met in December 1969 and again in January 1970 at Cal Tech, Pasadena, under the chairmanship of Professor E. Shoemaker. A report has been prepared for Dr. Petrone.

* Zenith Azimuth Coordinate – a quasi range-doppler coordinate system used for planning purposes.

Finally, we were requested to brief the Apollo 13 command-module pilot, Ken Mattingly, on our radar measurements of the moon, with the purpose of suggesting targets for the new Hycon camera (18-inch focal length) that will be carried for the first time by Apollo 13. The briefing took place at Kennedy Space Center in late January. One specific target in the vicinity of Taruntius has been entered on the mission plan, and other possibilities are still being investigated on the radar photographs.

IV. RADIOMETRIC TECHNIQUES

A. Instrumentation

The most important additions to the Radiometer Box system include a 35-GHz continuum radiometer, a 23.75-GHz parametric amplifier, and a 10-GHz spectral line radiometer.

The 35-GHz radiometer, built by Air Force Cambridge Research Laboratories (AFCRL) and on loan until early March 1970, is a Dicke-switched radiometer using a wide-band mixer followed by a 0.5- to 1.0-GHz IF amplifier and detector. Typical output noise fluctuations, integrated over 1 sec, are 1°K peak-to-peak. The older 35-GHz radiometer used at Haystack gave about 5°K. A special mode with reduced IF gain is provided for observations of the sun.

Installation of the 23.75-GHz degenerate parametric amplifier (owned by NASA/ERC) ahead of our 22- to 24-GHz radiometer gives a system noise temperature near 750°K for spectral line observation. Without the amplifier, the temperature is about 2.5 times higher. Although the main function of the radiometer is spectral line observations, a ferrite switch can be inserted ahead of the new amplifier for continuum observations.

The 10-GHz spectral line radiometer was built at Haystack by an M.I.T. graduate student for his thesis work. It is a Dicke-switched multifilter radiometer which measures 16 bands of the spectrum between 9.5 and 10.5 GHz. Low system noise temperature is achieved by a tunnel diode RF amplifier, the output of which is mixed down to a 1- to 2-GHz IF. The filters and their respective synchronous detectors follow the IF amplifier.

The Planetary Radar Box is also arranged to permit radiometric observations both at X-band (using the radar receiver suitably modified) and at K-band using a special offset feed. Both systems were extensively employed during the PR Box time in January.

B. Radio Astronomy

The most important radiometric result this quarter was the first successful VLBI (Very Long Baseline Interferometer) experiment conducted with the water vapor emission sources at 22.2 GHz. This experiment established that the H_2O sources have angular diameters of 0.05 arc second or less, which is comparable with the angular sizes of the OH emission sources previously studied. The following parallels between the OH and H_2O sources have been completely established: (1) the two types of emission sources very nearly coincide in position, (2) both kinds of sources are by far the most intense galactic emitters at their respective frequencies, (3) both are in some cases strongly polarized, although the polarization is predominantly circular for OH and linear for H_2O, (4) both types show instances of time variation, with H_2O variability being more widespread and more rapid. Now, from VLBI results, we can add another parallel: (5) both OH and H_2O sources have remarkably small angular diameter.

The VLBI experiments were performed in cooperation with investigators from the M.I.T. campus and the Naval Research Laboratory. Three antennas have been used: Haystack, the NRL 85-foot paraboloid, and the NRAO 140-foot paraboloid at Green Bank, West Virginia. All the data have been processed with the Haystack CDC 3300 computer. Thus far, interference fringes have been detected from the following sources: W3 (OH), W49, Orion A, and VY Canis Majoris. It is clear that the OH and H_2O sources constitute a new class of astronomical objects which we might term MASARS, extending the new terminology (quasars and pulsars) to these sources that evidently involve cosmic maser processes.

We are continuing our two long-term programs to measure the time variations in the water-vapor sources and those in 8- and 15-GHz emission from quasars and peculiar galaxies. These two programs provide a regular monitoring of the Haystack antenna performance, along with the astronomical data. We have established that the gain of the antenna at 8 and 15 GHz has not changed since the rerigging of the antenna surface in September and October 1967. Also, the water-vapor sources are sufficiently bright that we could measure the shape of the main antenna beam and the distribution of first sidelobes at 22 GHz. The main beam has very nearly a circular cross section at half-power level, and the highest sidelobe is 12 dB down from on-axis gain.

During January 1970, we undertook a joint observing program in which scientists of the AFCRL provided a radiometer operating at 35 GHz. This was the first time we have been able to operate at this frequency with adequate sensitivity to undertake observations of scientific interest. Measurements on the planet Jupiter have shown for Haystack an overall effective aperture of over 120 square meters and a half-power beamwidth of 1 arc minute at 35 GHz. We also measured the brightness distribution of the sun, the Crab Nebula, and the Orion Nebula.

DIGITAL COMPUTERS
GROUP 23

I. CIRCUIT AND NEW MACHINE DEVELOPMENT

A. Semiconductor Processing

Samples of the multi-level process chip (MLPC) have been examined with a scanning electron microscope to determine the nature of the "opens" in the third-level metal. These appear to be voids in the metal starting at the base of crossover steps where third-level metal intersects second-level metal lines. The problem appears to be related to the profile of the oxide over the second-level metal lines. The solution requires a change in the profile of the second-level metal line or in the oxide over the line. Both types of change are possible and the best solution will be incorporated into future designs.

An 80-gate load-chip wafer has been fabricated which contains chips having operable gate chains, but which in general are not perfect chips. This wafer was made before the improved second-level metal profile could be introduced. It will still be possible to obtain some useful circuit information from the wafer. These gate chains represent the first complete three-level devices we have received. Additional load-chip wafers and some 80-gate adders will be produced during the next quarter.

B. Computer-Controlled Wafer Probe

The major effort has shifted to a modification of the initial computer program to provide wafer maps which indicate the presence or absence of four simple functional outputs for each chip. This program is operational for a special metal-on-glass test pattern. The next series of measurements will be made using test semiconductor wafers where probe pressures and pattern sizes are more critical. Following this, tests will be made with a 12-point nonadjustable probe on a wafer of 3-bit parity circuits.

C. Circuit Development

Masks were designed for (1) a medium-scale integrated multiplier array, (2) the metallization patterns for the adder and multiplier on the 80-gate array, (3) the end connections for magnetic thin-film memory drive lines, and (4) a test pattern for the automatic wafer probes. The mask reticles for the microprocessor prototype adder using the 80-gate array were finished and sent to Philco for fabrication.

D. Interconnection of Integrated Circuits

Materials used for making electrical contact through vias in the dielectric layers on integrated circuit chip arrays have included conductive epoxies and evaporated metal. Most work has been done with chemically deposited metal where the aluminum chip pads are first coated with zinc, then nickel, and finally gold. The metals are applied prior to the application of chip interconnecting wiring.

Efforts at improving bonds between resin dielectric layers and the metal and glass of the chips include the use of silane coupling agents. Some success has been achieved with these materials.

Experiments with the selective exposure of resin for the dielectric layer has produced vias 1.3 mils square in a 2-mil-thick resin layer. This is compatible with the 2-mil pads currently employed in high-density chip circuitry.

Current efforts involve evaluation of metal-to-metal and resin-to-metal bonds, and measurement of the ohmic contact resistance between array wiring and chip circuitry under varying environmental conditions.

E. LX-1 Microprocessor

Changes have been made in the design of LX-1 due to the requirements of the TSP system. The connection between LX-1 and the core memory of the TSP system will be made through a new function box. This External Memory function box will provide paths for data and addressing information, via the A-bus (write data), B-bus (address), and D-bus (read data), that are the same as those provided by the Scratch Memory function box. The same op codes (READ MEM OP, WRITE MEM OP) will apply to both Scratch Memory and External Memory, with the differentiation made by the most-significant bit of the B-bus, B_{15}; B_{15}^{0} will specify Scratch Memory, and B_{15}^{1} will specify External Memory.

Microinstruction execute cycle times for the Scratch Memory will be fixed, predetermined times. During an execute cycle involving the External Memory, the LX-1 will go into a PAUSE state until a completion signal is received from the external memory, at which time LX-1 will continue.

F. Testing Computer

A simple display system which will present test results to the user while tests are performed was added to the testing computer. To facilitate testing, a digital-to-analog converter was installed and will provide a continuously variable voltage which can be used as an input signal to devices under test, or as a reference signal to comparators sensing the output of a device under test. In addition, a digital volt-ohmmeter was added to the system. Range, function, and triggering are under control of the test computer program or an operator.

A special device adapter was built for testing the Read-Only Memories and was successfully used to make a series of computer-controlled tests. Previous results were verified.

II. MAGNETIC FILM ENGINEERING

A. Word Lines

A new geometry of 1.3-mil-wide lines on 2-mil centers is being tested. Use of a 0.7-mil-wide tool permits wider tolerances in all scribing parameters.

Experiments with the Laboratory's "Mann Machine" for making pad pattern negatives from computer-produced punched tape have been encouraging. Scribing machine-to-negative registration is good and a considerable time saving can be realized by elimination of scribing the master pad patterns.

B. Word Decoding Matrix

Currently, the method of assembling 700 to 800 discrete diode chips into decoding arrays for LCM II is by attaching each chip to a word line pad with conductive epoxy and interconnecting the diodes by ultrasonically stitch-bonding 1-mil conductors to their top terminals. These arrays would then be potted in a soft silicone jel for environmental isolation, and a rigid cover bonded over the assembly for mechanical protection.

C. Digit Lines

The large scribing machine has been checked out and works well. Long digit substrates can be scribed as soon as they are available. All facilities for resist coating, baking, and etching these 52-inch-long substrates are complete.

D. Specifications for LCM II Magnetic Films and Keepered Digit Lines

The following specifications have been drawn up for the LCM II prototype memory which will have scribed 1-mil-wide word lines on 2-mil centers, and 6-mil-wide digit lines on 10-mil centers. The closed hard axis line structure will consist of (1) a 100-Å layer of Cr to improve adhesion, (2) an evaporated CoNiFe film with flux equivalent to a 1500-Å film having $B_s = 10^4$ gauss, (3) 5 μ of evaporated Cu, and (4) a 1500-Å electroless CoNiZn alloy for additional memory storage and hard axis closure. The properties required of both evaporated and electroless magnetic films are

$$H_c \geq 30 \text{ Oe} \quad , \quad H_k \leq 60 \text{ Oe} \quad , \quad \alpha_q \leq 2^0 \quad .$$

Digit lines will have a 10,000-Å evaporated 70% Ni-30% Fe film ($H_k \leq 10$ Oe) in back of the digit lines which will be plated with copper 1-mil thick. Side closure will probably be provided by a slurry of carbonyl Fe. The signal obtained at the bit using this keepered configuration is 260 μV, which is two times that obtained in the LCM I. Word currents of 400 mA, and digit currents of 150 to 250 mA are required.

E. Magnetic Film Plating

A high-temperature stabilizing anneal in a parallel magnetic field reduces the anisotropy of the high anisotropy films by 40 percent or more, giving highly inverted films with very square hysteresis loops, and at most small charges in coercivity and dispersion. Most of the change occurs in a short time; it is as yet uncertain whether other long-term changes (other than those due to oxidation and copper grain growth) continue to occur.

F. Optical Testing of Magnetic Films

Mechanical design is completed and electrical design partially completed on an optical B-H looper for testing the magnetic keeper layer on the 52-inch-long glass digit substrates for LCM II. The drive coils and optics will scan the length of the substrate under an automatic motor drive, while the magnetic parameter being measured is registered on an x-y recorder.

G. Word Noise Experiments

A memory stack the size of LCM I was assembled with digit lines on 0.040-inch-thick glass substrates. As previously reported, noise due to capacitive imbalance was very low. Some long-range spacing variation was observed, but with no deleterious effects. The importance of maintaining close spacing to a ground plane, in order to minimize inductive coupling between word lines and effects of surge currents at edge digit lines, was demonstrated.

H. "Transformerless" Sense System

The requirement of a balanced-bridge configuration to keep digit drive out of the sense amplifier can be met with a 4-transistor array, connected as two separate differential amplifiers, as an input stage. Large, high-frequency RF transistors operating at high emitter currents (12 mA) have given a signal-to-random-noise ratio of 30:1 when used with LCM I digit lines and LCM I signals (130 μV, 35 nsec). This ratio is within 10 percent of that obtained with a transformer-coupled system.

The sense-circuit common-mode rejection and digit recovery are about as good as those of the transformer-coupled system of LCM I. Performance is dependent upon transistor matching; an integrated-circuit version, which would be the only practical arrangement because of circuit complexity, should show substantial performance improvement.

III. COMPUTER SYSTEMS

A. Performance Measurement

A new mechanism for triggering a user program at interrupt level has been implemented in the APEX time-sharing system on TX-2. The mechanism is based on four new inputs to the encoded interrupt detector on TX-2: the outputs of the two "sync sources," and the overflow bits on the two event counters. The sync sources are hardware devices for monitoring the state of TX-2's control registers. Each sync source outputs a pulse each time the specified control register(s) reach(es) the indicated state(s). For example, a sync source may be set up to output a pulse each time the program counter equals 60135, or each time an LDA instruction is executed, or each time any instruction is executed. Each sync source is the input to one of the "event counter" registers, which may be read or written under program control.

B. System Performance

An experimental, interactive program has been written to illustrate one application area for the new facility: software measurement. A user may specify a quantity to measure (e.g., program counter, index register contents, working-set size, contents of a specified register, etc.) and several value ranges for the quantity. He may also specify an exact or average frequency for sampling the value of the quantity, based on the state of one event counter (e.g., "every 7000 counts, on the average"). As the application program runs (entirely undisturbed), the monitoring program will sample the indicated quantity at the indicated frequency, and dynamically plot a histogram (on the storage scope) of the number of occurrences of the value in each specified value range.

This program has been used to plot program counter samples to help locate gross computational bottlenecks in a particular large, complicated, working LEAP program. Further analysis of apparent bottlenecks in the LEAP run-time system was made by refining the address ranges for program counter values. We found that two very small system subroutines accounted for a huge amount of the computation time; careful recoding of these routines took an hour, and a 30-percent increase in overall speed was realized. Further examination of the situation showed two things:

(1) One of the built-in LEAP system parameters was suboptimal and should be modified for this particular case.

(2) The global strategy in the LEAP program could be trivially modified to yield significant increase in efficiency.

The results were (1) a promise from the LEAP system designer that users would be allowed to determine (under program control) the previously fixed parameter, and (2) a promise from the LEAP programmer that he would encode the strategy modification. Subsequent trial change to the system parameter yielded a total speedup of 41 percent. Whether this strategy change will help has not yet been determined.

Similar techniques were applied to several other large programs: The BCPL compiler was accelerated by 37 percent — the structure-input phase of the mask program by 21 percent.

Another usage of the program was to measure average working-set size and the number of file setup requests for a particular large LEAP computation as a function of an internal LEAP system parameter. We found that the existing value of the parameter could not be much worse for the particular case; the working-set size could be conveniently decreased by 12 percent at the same time that the total number of file setup requests could be decreased from 910 to 160. Again, the LEAP system designer agreed to allow the user to specify the parameter. Also, closer scrutiny indicated that a simple change in strategy inside the LEAP system would help, in general.

PSYCHOLOGY
GROUP 25

I. PROVISION FOR MAN-MACHINE INTERACTION ON THE IBM 360/67

A. Reckoner/Mediator System Improvements

Aside from routine maintenance of Reckoner and Mediator programs, the main effort of the past quarter has been to provide an automatic graph plotting capability. That is, the user specifies pairs of functions, and the program performs automatic scaling – determining the number, location, and labeling of tick marks – and plots the points on the ARDS terminal with appropriate legend. The program has been designed in a table-driven fashion, which will allow great flexibility to adapt to other graph-plotting devices and to permit control of the format of the elements that make up the graph. In addition, a start has been made on providing essential debugging and utility routines for the Reckoner. The ARDS is presently running at high speed (1200 bauds) direct wired to the computer, and remote operation at this rate has been successfully demonstrated. The Laboratory responded to an invitation to demonstrate the system at a booth for educational exhibits at the annual convention of the American Association for the Advancement of Science in Boston in December 1969.

B. Field Test of the Reckoner/Mediator

Planning and other work is being done in preparation for a Laboratory-wide field test of the Reckoner/Mediator system. We hope that a class of users will emerge that needs and uses a fast-response, interactive computing facility. For these users, the Reckoner/Mediator is expected to provide an environment where the writing of new programs is at a minimum. This should be the result of providing the Reckoner a general set of computational and array manipulating programs which can be used alone or combined into larger computational units to solve a wide range of problems. In addition, we will make an effort to foster the advantages of "coherent programming" by insuring that new programs are made available to the whole community of users. Our goal is to create a self-enriching problem-solving environment, responsive to the needs of the users at the Laboratory.

II. PROVISION FOR MAN-MACHINE INTERACTION ON TX-2

In APEX, the executive system monitors each user and records the files that he references while running. A user's "working set" is defined as the set of files that he referenced during his last 2 sec of processor time (subject to a variable maximum). The Core Storage Allocation routines retain each active user's working set files in core to the extent space allows, and guarantee that they will be in core when he is again given processor time. (Highly interactive users such as those doing editing on a scope are not included. They use only one or two small files which are frozen in core for them.)

During the past quarter, a detailed analysis of the efficiency of this paging scheme was begun using the Data Collection Device. Most time-sharing systems use a demand paging scheme,

i.e., pages or files are brought into core only when referenced via a page fault mechanism. Thus, it would seem profitable to analyze our system carefully and compare it with the method in general use. An analysis may also uncover weaknesses in our algorithms and lead to their correction.

Initial results suggest the "working set" notion is quite efficient, but additional data must be gathered before we can justify any firm conclusions. A report will be prepared, detailing the paging algorithm and its performance characteristics.

III. HUMAN INFORMATION PROCESSING

Initial latency data on judgment of the magnitude of numbers have been obtained. In a typical run, a subject has a criterion number in mind. He is to respond either by pressing a "high" or "low" button when a printed two-digit number appears if it is higher (or equal) or lower than the criterion. The curves of latency as a function of stimulus number reveal the nature of the judgment process. For example, with a criterion of "50," latencies are on the order of 0.3 to 0.4 sec; with "55," they are on the order of 0.6 to 0.7 sec, except that longer times of 0.8 to 0.9 sec occur for stimuli "50" to "59." We hypothesize that the subject first judges whether the more-significant digit is a "5" or not. If so, he makes a judgment based on the less-significant digit. If the first is not "5," he judges whether it is greater or less. We plan to instruct subjects in other modes of information processing, and to examine the consistency of the resultant latency measures.

IV. EDUCATIONAL METHODS

A sizable portion of the group effort during this quarter has been in the Educational Technology project, which is reported on p. 19.

COMPUTER SYSTEMS
GROUP 28

I. COMPUTER CENTER DEVELOPMENT

During this quarter, a project was begun to support a virtual 360/67 to the extent required to run CP itself in a virtual machine under CP. This facility will enable development and maintenance to be carried out concurrently with the use of CP, the system which provides time-sharing services to the Laboratory. This project is well under way and initial testing has already begun.

CP now supports an ARDS graphics terminal on a 1200-baud telephone line providing high-speed graphic display output. In addition, multiple storage tube displays are supported via a shared transmission line to a PDP-1 computer which is programmed to serve as the display control unit.

Because of the release of the IBM 360/40 computer at the end of this quarter, the LLMPS operating system will be run under CP. It has been demonstrated that the CalComp plotters, the VIDAR data logging system, the LES data monitoring facility, and the link to the Univac 1219 computer can be supported by LLMPS running under CP. The extent to which this support will be a satisfactory replacement for the 360/40 under full CP load conditions is yet to be determined.

Work on BMS (the batch monitor system) has progressed so that CMS procedures can now be executed under the batch system and thus any program or command run under CMS can also be run under BMS. A new command, SETUP, can be issued to request the mounting of tape during a BMS run. The tape error recovery procedures are still rudimentary and must be improved before tapes can be reliably processed under BMS.

One of the prime objectives of a time-sharing system is to increase programmer productivity during program development. To aid in the development of Fortran programs, a Fortran Debugging System (FDS) is being implemented which will enable the programmer to set branch points at selected statements in his program, and to display or modify the values of symbolic program variables during execution. The FDS programmer accesses these debugging facilities via an easy-to-use command language based upon the symbolic notation in which the source program is written.

OS/360 – HASP, the IBM batch monitor which still handles the bulk of the Laboratory's processing load, is running with one copy of the disk packs on which user programs are stored. Both CPU's access these packs when both are running OS. In addition to the greater convenience of updating program libraries, the procedures for using these libraries have been improved. The changes are expected to encourage greater use of disks for program storage.

The new OS-MFT-HASP system is running reasonably well and has improved turn-around time. However, this system has many more "bugs" than our long-established OS-PCP system had. A considerable amount of effort will be required in the next quarter to bring HASP up to the reliability level of PCP.

Because CP provides a convenient tool for performing systems programming, work has been done to make it more usable for OS. The normal mode of operation of OS under CP involves

going back and forth between CMS and OS. Since OS takes a very long time to start up under CP, development of a fast method of starting which just loads core-image pages of a ready system has been in progress. This method is called "IPL by name" and will also be used by CMS and LLMPS.

Because of the attractions of multiprogramming, OS-MVT-HASP is being investigated. Ideally, two or more jobs would be run concurrently – with the I-O bound parts of one overlapped by the CPU bound parts of another. Unfortunately, MVT appears to be designed for running small, short-duration jobs with large amounts of memory (around 298K bytes is one IBM estimate) devoted to the system. It may be possible, however, to construct an MVT system which does not occupy so much core and accommodates our relatively long-running jobs well. Applying the numerous and lengthy formulas published by IBM for calculating MVT core requirements, leads to the conclusion that it is possible to construct a system not much bigger than our current MFT. Such a system is being generated to determine if the formulas are accurate and how well a small MVT would run Lincoln's job mix.

EDUCATIONAL TECHNOLOGY

I. INTRODUCTION

A number of Laboratory studies conducted over the past several years have suggested the feasibility of developing teaching machines, or educational terminals, that will significantly reduce the present costs of vocational and basic skill training. A program directed at such a development was initiated during the past quarter.

The Lincoln system, as currently envisioned, would employ photographic (microform) techniques for the storage of audio as well as visual data and for the storage of course-specific control information. Through this means, it should be possible to achieve much of the flexibility and power of a conventional CAI system without the requirement for a large computer and a wideband communication system.

The system will be optimized for handling technical training material, and a close working relationship with the Air Training Command has been established. In particular, advantage will be taken of the large corpus of tested instructional material which has been developed by the Air Force.

II. SYSTEM DESIGN AND HARDWARE DEVELOPMENT

The basic system as presently conceived assumes that

(a) Positive transparencies will be projected directly onto the terminal display screen.

(b) Material will be random-access audio-visual, with frame-frame access time on the order of 1 sec.

(c) Audio material content will be on the order of 60 sec per frame.

(d) Visual material will be text and graphics, including halftones, on an $8\frac{1}{2}$- × 11-inch format.

(e) Program branching logic will be stored photographically with each frame.

(f) Terminal keyboard will be simple, allowing multiple-choice responses and limited interaction with the program.

(g) Existing educational material in the form of programmed instructional text, educational TV, film, etc., will be adapted for use with this system.

(h) General requirements are reliability, cost, human engineering, and performance, in that order. The terminal must be easy to use for periods of several hours.

In order to evaluate these design features and system parameters, a terminal is being constructed with commercially available components. The principal components of the system are four Minnesota Mining and Manufacturing "sound-on-slide" 35-mm projectors under control of a PDP-8/I computer. The projectors have been modified to handle 50 slides per tray, affording a 200-frame lesson with average access time of 1 sec and maximum access time of 3 sec. The projectors are mounted in a student console. The images are selected with mirrors and projected on a screen at about page size ($8\frac{1}{2}$ × 11 inches). A student control box and loudspeaker are provided. The audio content per frame has been increased from 35 to 60 sec by reducing

the recorder head rotation speed. All the branching is under direct control of the computer in this version. All control and status information, along with time tags, will be recorded on a Model 1500 incremental tape recorder for subsequent analysis of student/lesson interaction.

Approximately 90 percent of the breadboard components have been completed, and final assembly will start during February. The Phase I terminal will be operational by May of this year and available for use with lesson material now being developed. Development of the Phase II (microform) terminal is proceeding concurrently.

III. SOFTWARE DEVELOPMENT

The area of software development covers all topics directly bearing on the relation of man to machine.

Specifications have been made for monitoring student and machine performance during a learning session. Every event, the kind of action, and the time of occurrence will be recorded on magnetic tape for subsequent analysis on the Laboratory TX-2 or IBM 360/67 computer facilities. For reasons of flexibility and economy, most of the control logic of the Phase I machine resides in its computer. All branching logic unique to a particular lesson, however, will be contained in a single table, which is derived from information provided by the lesson author. This scheme simulates the requirements on the Phase II machine that branching information will reside on the microform itself. Detailed program specifications in all areas of control and recording are being worked out.

For the student console, considerable effort has gone into organizing control logic, displays, and keyboards to assure that they are easy to learn and that they function smoothly. The design of the student control panel illustrates the requirements that have been met. The right-hand side of the response panel provides for actions within a frame. Here the student may make response selections, ask for a repeat of audio information, or instruct the machine to go on to the next audio/visual information in case no other response is required. If the student wants to branch elsewhere, he uses controls on the left side of the panel. He may select "Index," a frame which lists lesson topics by frame number. He may proceed directly to any frame by frame number. A "Go Back" button provides return to the original location.

It has been shown that approximately 100 hours of preparation go into each hour of instruction in the teaching machine environment. This has led to consideration of facilities for the support of course authors as an integral part of the proposed system. Two areas have received attention during the current quarter. An audio recording studio, specially designed for authors to make talking slides, is under construction and will be operational shortly for the Phase I machine. Also, a system is being developed for the author (or his agent) to insert and edit control tables in the computer by means of a teletype input. The preparation of visual frame material is a more complex subject that is still under consideration. A survey of existing facilities is being made, including computer peripherals such as displays and printers, computer systems such as text editors, file management, and graph plotting systems, and standard Laboratory services such as the Photo Service and Publications Groups. Some of these facilities, supplemented by a few people to organize and coordinate efforts, will serve as the initial means of production for lesson materials for the Phase I machine. Preparation of materials for a large field test in Phase II of the program will require a substantial development effort with the ultimate goal of providing more efficient facilities to support course authors.

Work has started on the production of two lesson units of 1 to 2 hours each for the Phase I equipment. The first unit is based on an Air Force programmed instruction package covering the principles of amplitude modulation and single-sideband (SSB) communications. This work has been inspired by two trips to Keesler Air Force Base to observe Air Training Command teaching procedures and to discuss teaching methods. The second unit will be concerned with the Cyrillic alphabet and pronunciation of Russian words. The SSB unit will provide our first experience from which to judge the adaptability of the machine to Air Force technical training. The Russian lesson, authored by an expert language teacher, will test the adaptability of these techniques to a different type of instructional material.

RADAR
DIVISION 4

INTRODUCTION

The Division 4 General Research program has been reoriented to the problems of Air Traffic Control (ATC). The objective of the present limited program is to obtain a better understanding of the problems of ATC, particularly those of surveillance and communications, and to work toward the development of a new high-capacity data acquisition/communication (DA/C) system for the future which will be compatible with both civilian and military needs.

During the present reporting period, most of the effort has been directed toward understanding present and future data and communication requirements for ATC.

H. G. Weiss
Head, Division 4

AIR TRAFFIC CONTROL

I. INTRODUCTION

The Air Force-sponsored ATC work at Lincoln Laboratory was motivated by the requirement that the military beacon system be compatible with the civilian air traffic control surveillance system. The civilian system as presently configured is beginning to approach the limits of its capability in some areas, particularly the New York and Los Angeles Terminal areas. As a result of traffic delays arising from near saturation of the ATC system, considerable thought has been given recently to upgrading the entire system, including the development of a new data acquisition system, to eventually replace the present system. It is important that any new system retain compatibility with existing equipment for a sufficient length of time that the economic burden of conversion is not intolerable. The Air Force has recently equipped the great majority of its fleet with compatible beacons and is therefore directly concerned with new requirements imposed by civilian ATC system evolution.

In the summer of 1969, a study group was formed at M. I. T. for the purpose of becoming familiar with the operation and problems of the present ATC system. Members of Lincoln Laboratory, Instrumentation (now Draper) Laboratory, Electronic Systems Laboratory, and the Flight Transportation Laboratory participated. Members of the study group visited a number of ATC facilities including the Nashua FAA Center, the Logan Tower and Radar room, the Kennedy Tower and Common IFR room, NAFEC (National Aviation Facility Experimental Center) in Atlantic City, the ARTS installation at Atlanta, and made several visits to the FAA/DoT in Washington. During this study period, the DoT/ATCAC (Department of Transportation Air Traffic Control Advisory Committee) report became available in draft form. Much of the group's work consisted of understanding this report and its recommendations. The study group received briefings from Ben Alexander, the Chairman of the DoT/ATCAC, and from its secretary, Lawrence Goldmuntz. A number of other informal briefings were given, including one by Logan air traffic controllers.

Recent work at Lincoln Laboratory has been concerned principally with the data acquisition and communication functions of air traffic control.

II. SUMMARY OF ATC WORK TO DATE

Most of the effort of Lincoln Laboratory to date on ATC has been spent on becoming familiar with all aspects of the present ATC system, its equipment, its operation, and its problems. The DoT/ATCAC report (which became available in draft form in October 1969) has provided a valuable introduction to the field of ATC. Initial efforts to understand the specific recommendations of that report and its appendices have since grown into Lincoln Laboratory study efforts referred to as Requirements Analysis and Beacon/Data Link Design Studies.

Independent of and prior to the release of the recommendations of the DoT/ATCAC, a multipath propagation experiment was initiated at Lincoln Laboratory to obtain some basic data important to the design of digital data links between aircraft and ground stations. A brief description of these work areas follows.

A. Multipath Experiment

An experimental program is now under way at Lincoln Laboratory to measure multipath characteristics at L-band associated with various antenna characteristics and siting locations. The aims of the measurement program are:

(1) To provide multipath channel models for use in the analytical studies of ranging and digital communications techniques and in antenna design,

(2) To assess the difficulty of the siting problems associated with various types of ground stations being considered for the improved beacon system.

In the experiment now under way, the L-band channel impulse response is measured by "sounding" the channel with very short (20- to 40-nsec) RF pulses. This first phase of the experiment will provide good insight into the severity of the multipath problem that can be expected at various types of sites.

Later phases of the experiment will provide data necessary to design antenna patterns to suppress multipath, to design a radio-location system for airport surface surveillance, and to assess the effects of multipath on accurate monopulse azimuth estimation and on satellite-aircraft links.

B. Requirements Analysis

The objective of the requirements analysis is the determination of the data quality and data rates required for present and anticipated functions which will be performed by the ATC system. This work is thus independent of the type of DA/C system that is selected for development, and is necessary to assess the feasibility of data acquisition system designs. Hence, this work was started early in Lincoln's ATC program and will continue for some time in order to provide more complete analyses of all ATC functions using improved models.

The recommendations of the DoT/ATCAC report for an upgraded radar beacon system were based on an analysis of data quality and data rates for certain critical ATC functions. Certain of these analyses which played an important role in influencing the ATCAC recommendations have been examined in detail in the Lincoln Laboratory effort. In some cases, the analyses have been redone to include important aspects of the problem not considered in the original analysis. The most notable example is the analysis of the traffic monitoring functions. This class of problems has been reformulated to include false-alarm probabilities for fixed probability of detecting certain hazardous situations or events. The first applications of this formulation have been made to the problems of monitoring approaches to closely spaced parallel runways and to the collision avoidance problem.

C. Beacon/Data Link Design Problems

The design and development of a discrete addressable beacon/data link will be the major activity in the realization of an adequate DA/C subsystem for the ATC system. The DoT/ATCAC report summarized many of the shortcomings of the present system and suggested some possible solutions, but did not develop these suggestions in detail.

The ground-based interrogator is responsible for a number of the performance limitations in the present surveillance system. Lincoln Laboratory has done a preliminary study of interrogator antennas, considering (1) circular phased arrays, (2) polygon-shaped flat-faced phased arrays, and (3) multisided mechanical rotators. The phased arrays allow great beam agility and consequent control of data rates but are many times more expensive than mechanical rotators. Either type of antenna can provide (1) elevation pattern control to reduce vertical lobing, (2) greater angular resolution which is required in high-density areas, and (3) improved angular accuracy through use of monopulse angle-estimation techniques.

During this reporting period, Lincoln Laboratory gave assistance to the FAA in preparing a request for proposals for an experimental phased-array antenna which would be a first step in providing the surveillance capability required in high-density areas.

The continuing program will focus more sharply on establishing antenna design tradeoffs, i.e., cost vs performance, and will begin to look at other aspects of the beacon/data link problem which have, up to now, been largely ignored.

III. FUTURE WORK

The involvement of Lincoln Laboratory in ATC will be focused primarily on the over-all ATC system engineering and, in particular, on the design and development of a new data acquisition and communication subsystem providing digital data link capability between aircraft and ground. The future work can be separated into the following analytical and experimental areas.

Systems Analysis – to determine the requirements imposed on data quality and data rates by present and anticipated ATC system functions, and to translate these requirements into parameters of specific data acquisition system configurations.

Multipath Propagation Experiment – to establish multipath models for signal design, antenna pattern design, and ground station siting.

Signal Design – to determine modulation and coding for unified signal formats for both data acquisition and communication in the multipath, multiple-channel user environment.

Radar Beacon/Communication System – to study means of improving the present radar beacon ground equipment in the very near term, and to develop and demonstrate the capabilities of a new compatible beacon system with digital data link capability.

Advanced Technology – to study and develop the critical components of more advanced data acquisition systems, such as trilateration systems and satellite-based systems.

OPTICS
DIVISION 5

INTRODUCTION

This section summarizes the General Research efforts of Division 5 for the period 1 November 1969 through 31 January 1970. A complete presentation of the Optics effort may be found in the quarterly Optics Research Report and in the Semiannual Technical Summary and Quarterly Letter Reports to the Advanced Research Projects Agency.

R. H. Kingston
Head, Division 5

DIVISION 5 REPORTS ON GENERAL RESEARCH

15 November 1969 through 15 February 1970

PUBLISHED REPORT

Journal Article*

JA No.			
3491	Perturbation of the Refractive Index of Absorbing Media by a Pulsed Laser Beam	P. R. Longaker M. M. Litvak	J. Appl. Phys. 40, 4033 (1969), DDC AD-699270

* Reprints available.

OPTICS AND INFRARED
GROUP 53

The CO_2 laser radar has been modified to include a means of generating angle error signals at 10.6 μm for use in automatic angle tracking. Installation and checkout of the aircraft tracking configuration of the frequency tracking receiver at the Firepond Facility has been completed, and it has been used to frequency-track aircraft targets. Various methods of daytime optical beacon tracking have been examined, and a promising system is being implemented.

The modification of the high-power laser amplifier has been completed, and it is in routine operation at a CW power output in excess of 1 kW.

Three new piezoelectrically tuned 15-W stable laser oscillators have been built and tested. A pair of the stable lasers were locked together with a 5-MHz offset to simulate the requirements for the CO_2 radar. Two of these new oscillators have been installed as the local and master oscillators.

Experiments to measure the Lamb dip associated with CO_2 lasers have been continued. Precise data were obtained for pressure broadening in CO_2 between 0.01 and 0.8 torr. The effect of power broadening has also been accurately determined. In addition, locking of CO_2 lasers to the line center has been achieved. More detailed results will soon be submitted for publication.

Frequency response curves for several $Pb_{0.80}Sn_{0.20}Te$ detectors were obtained at 77°K by the heterodyne technique with two tunable CO_2 lasers at 10.6 μm. The gain curves are flat over the entire 30-MHz tuning range, and these detectors have now replaced Ge:Au for the master oscillator-local oscillator offset frequency detector in the laser radar system and in other heterodyne experiments.

A substantial increase in output power in a single spatial mode from a CW $Pb_{0.88}Sn_{0.12}Te$ diode laser was obtained by altering the reflective quality of the cleaved end faces. By reducing the cavity Q everywhere except near the center of the junction plane, nearly all the laser energy can be concentrated in the lowest-order Gaussian mode.

ENGINEERING
DIVISION 7

INTRODUCTION

The Engineering Division's support of the General Research program appears in the design of devices for solid state research, in the upgrading of mechanical facilities at Haystack Hill, and in research and development concerning new techniques in microelectronics, principally integrated circuits.

J. F. Hutzenlaub
Head, Division 7

DIVISION 7 REPORTS ON GENERAL RESEARCH

15 November 1969 through 15 February 1970

PUBLISHED REPORT

Meeting Speech*

MS No.			
2612	A Flexible Automated Mask Generation System	N.B. Childs	NEREM Record (1969)

* Titles of Meeting Speeches are listed for information only. No copies are available for distribution.

MECHANICAL ENGINEERING
GROUP 71

I. SOLID STATE RESEARCH

A. Light Emission Probe

A light emission probe was designed and fabricated to permit measurement of the optical transmission of $ZnTe_{1-x}Se_x$ at 77° and 300°K. The purpose of these measurements was to determine the energy gap as a function of alloy composition.

Samples in the order of 30 to 70 μm thick were prepared and mounted on two sliding collimator plates which were attached to tubular epoxy motion transmitters. No distortion of the sliding mechanism at 77°K was observed. The data obtained confirmed earlier reports of a minimum in the energy gap as a function of composition, which proves the probe to be quite accurate for this sort of measurements.

High-temperature measurements of this type are to be performed as soon as equipment is available. Design has been completed and manufacture of the equipment is in progress.

CONTROL SYSTEMS
GROUP 76

Since its inception, the Haystack antenna has suffered from marginal pointing servo performance. The original design for each axis featured a large servo valve metering flow from a constant pressure source to four piston-and-cam-type hydraulic motors connected in parallel. The motors, designed for automatic machine tool use, proved unsuitable for use with large overhauling loads. Several motors failed; therefore, velocity, accelcration, and bandwidth of both the azimuth and elevation servos were limited to barely usable minimums in order to reduce the failure rate.

After extensive testing with a simulatcd load incrtia, a ncw type of hydraulic motor was selected. The servo valve was replaced with a variable displacement pump to improve operation at very low speeds and provide complete isolation bctween the two axes. Tachometer and differential pressure fecdbacks were added to reduce the effects of component timc constants and linearize system response.

During December 1969, thc new servo was installed in the azimuth axis; thorough simulator testing of the new system minimized the shutdown timc required. The desired performance of 2.5°/sec velocity and 2°/sec/sec acceleration was achieved, and intcgral compensation rcduced dynamic error at earth's rate to its theoretical limit of ±1 bit of the 19-bit shaft angle encoder. Installation of the new elevation servo is planned for March 1970.

MICROELECTRONICS GROUP 77

The past quarterly period has seen more emphasis on research and development programs than on service-oriented integrated circuit tasks. This is primarily the result of disruption due to the relocation of some of the sections within the Integrated Circuit Facility and the loss of some support personnel.

Semiconductor work has centered around new processing techniques for passivating mesa structures, and the results so far are extremely promising. A parallel effort is under way to improve the mounting process for mesas, particularly Impatt diodes.

The very small geometry (1 to 5 μ) Schottky barrier devices have been developed to the point of prototype modeling with good results.

The beam lead substrate technique of assembling large numbers of chips has been used successfully in mounting 30 to 40 chips in a 1-inch-square substrate. These structures have been fabricated in a rigid (alumina) format, as well as in a nonrigid format (Kapton).

The thin-film area has been relocated in the new Class 100 clean room and is expected to be operational within the next month. Two new research programs are being implemented: the first will examine the effect of residual gas composition on the rate of photoresist removal during sputter etching, while the second will develop sputtered tantalum resistors in partial pressures of oxygen and/or nitrogen.

Thick-film techniques have been pursued, particularly to obtain fine-line metalization. Special substrate techniques such as buried-layer metalization, tapered feedthroughs for microwave networks, and edge metalization have been successfully developed.

The laser scanning system for the evaluation of semiconductor chips has been further developed during this period. The system has recently been used to inject signals into long shift register semiconductor arrays.

The computer-aided section has installed the D. W. Mann Company pattern generator and photorepeater, and both are in operation. These units are currently producing about 10 to 15 photographic masks per day. Current problems relate to the handling and processing of the masks in order to minimize pinholes and other flaws. The new equipment requires changes in the Mann Plott computer program, and these are currently in progress.

Work on the digitizer program, which transfers coordinate information from a drawing, has continued and is presently in the debugging stage.

The double-precision version of the CIRCUS program has been completed and distribution of the program has begun. An on-line version of CIRCUS for use on the Laboratory's time-sharing system has reached the stage of final debugging and documentation. This program will soon be available for circuit engineers as an aid in circuit design.

Personnel from the Integrated Circuit Facility have aided in the installation of a scanning electron beam microscope to be used for diagnostic analysis and fine-line (submicron) processing.

SOLID STATE
DIVISION 8

INTRODUCTION

This section summarizes the work of Division 8 from 1 November 1969 through 31 January 1970. A more detailed presentation is covered by the Solid State Research Report for the same period.

A. L. McWhorter
Head, Division 8

P. E. Tannenwald
Associate Head

DIVISION 8 REPORTS ON GENERAL RESEARCH

15 November 1969 through 15 January 1970

PUBLISHED REPORTS

Journal Articles*

JA No.			
3369	Inversion Asymmetry and Warping-Induced Interband Magneto-Optical Transitions in InSb	C.R. Pidgeon† S.H. Groves	Phys. Rev. 186, 824 (1969)
3423	Brillouin Scattering Study of Acoustic Attenuation in Fused Quartz	A.S. Pine	Phys. Rev. 185, 1187 (1969)
3444	Derivation of a Quasiparticle Transport Equation for an Impure Fermi Liquid at Low Temperatures	J.L. Sigel	Phys. Rev. 186, 182 (1969)
3483	X-Ray Diffraction Studies on Zn_3As_2 and Cd_3As_2 at High Pressure	M.D. Banus M.C. Lavine	High Temperatures-High Pressures 1, 269 (1969)
3485	Velocity and Attenuation of Hypersonic Waves in Liquid Nitrogen	A.S. Pine	J. Chem. Phys. 51, 5171 (1969)
3520	An On-Line Data Recording System	W.E. Krag N.L. Daggett R.N. Davis F.E. Perkins†	Rev. Sci. Instr. 40, 1606 (1969)
3525	Magnetic Ordering Effects in the Ultraviolet Reflectance of EuS and EuSe	W.J. Scouler J. Feinleib J.O. Dimmock C.R. Pidgeon†	Solid State Commun. 7, 1685 (1969)
3541	Magnetic Ordering Effects on the Reflectivity of EuS and EuSe	C.R. Pidgeon† J. Feinleib W.J. Scouler J. Hanus J.O. Dimmock T.B. Reed	Solid State Commun. 7, 1323 (1969)
3558	The Intensities of Spin Wave Resonance Modes in Thin Films	R. Weber P.E. Tannenwald C.H. Bajorek	Appl. Phys. Letters 16, 35 (1970)

* Reprints available.

† Author not at Lincoln Laboratory.

JA No.			
3585	Residual Impurities in High-Purity Epitaxial GaAs	C. M. Wolfe G. E. Stillman E. B. Owens	J. Electrochem. Soc. 117, 129 (1970)
3586	Optical Observation of Magnetic-Field-Induced Spin Alignment in Antiferromagnetic EuTe	J. Feinleib C. R. Pidgeon*	Phys. Rev. Letters 23, 1391 (1969)
3597	The Hubbard Model: Insulator or Conductor for Narrow Band Regime	R. A. Bari R. V. Lange*	Phys. Letters 30A, 418 (1969)
3612	Theory of Surface Plasmon Excitation in Low Energy Diffraction and in Photoemission	K. L. Ngai E. N. Economou* M. H. Cohen*	Phys. Rev. Letters 24, 61 (1970)
3624	Interstellar Masers	D. F. Dickinson* M. M. Litvak B. M. Zuckerman*	Sky and Telescope 39, 4 (1970)
MS-2389	Raman Scattering by Magnetic Excitations in $RbNiF_3$	S. R. Chinn H. J. Zeiger J. R. O'Connor	J. Appl. Phys. 40, 1603 (1969)
MS-2615	Magneto-Optics	J. G. Mavroides	Proceedings of International Conference on High Magnetic Fields and Their Applications, Nottingham, England, 17-19 September 1969, High Magnetic Fields and Their Applications (1969), pp. 1-37
MS-2623	Laser Beam Trapping and Non-Linear Interactions in Semiconductors	A. Mooradian	NEREM Record (1969)

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UNPUBLISHED REPORTS

Journal Articles

JA No.			
3551	Niobium Monoxide $3Nb + Nb_2O_5 \rightarrow 5NbO$	T. B. Reed E. R. Pollard* L. E. Lonney* R. E. Leohman* J. M. Honig*	Accepted by Inorg. Synth.

* Author not at Lincoln Laboratory.

JA No.			
3552	Resistivity, Magnetoresistance, and Hall Effect Studies in VO_x $(0.82 \leq x \leq 1.0)$	J. M. Honig* W. E. Wahnsiedler* M. D. Banus T. B. Reed	Accepted by J. Solid State Chem.
3557	Hall Coefficient Factor for Polar Mode Scattering in n-Type GaAs	G. E. Stillman C. M. Wolfe J. O. Dimmock	Accepted by J. Phys. Chem. Solids
3563	Interdiffusion in Lead Selenide	R. W. Brodersen* J. N. Walpole* A. R. Calawa	Accepted by J. Appl. Phys.
3568	Atom Movements: Diffusion	R. F. Brebrick	Physics & Chemistry of Solids: An Introduction, ed. by P. F. Weller (M. Dekker, Inc., New York)
3577	Reinterpretation of $^4A_2 \rightarrow {}^2E$ Exciton Spectra in $YCrO_3$	J. W. Allen	Accepted by Solid State Commun.
3579	Photoluminescence Due to Isoelectronic Oxygen and Tellurium Traps in II-VI Alloys	G. W. Iseler A. J. Strauss	Accepted by J. Luminescence
3587	Split-Off Valence Band Parameters for GaAs from Stress-Modulated Magnetoreflectivity	M. Reine* R. L. Aggarwal* B. Lax* C. M. Wolfe	Accepted by Phys. Rev.
3590	Thermodynamics and Determination of the Liquidus-Solidus Gap in Homogeneous, Monotonic Alloy Systems	J. M. Steininger	Accepted by J. Appl. Phys.
3602	Laser Raman Spectroscopy	A. Mooradian	Accepted by Science
3606	High Temperature Electrical Properties of CdSe: Evidence for a Native Donor	F. T. J. Smith	Accepted by Solid State Commun.
3608	Vapor-Crystal Equilibrium and Electrical Properties of HgTe	A. J. Strauss R. F. Brebrick	Accepted by J. Phys. Chem. Solids
3610	Localized One-Electron States in Perfect Crystals As a Consequence of the Thermal Single Determinant Approximation	T. A. Kaplan P. N. Argyres*	Accepted by Phys. Rev.
3611	Magnetic Susceptibility of Europium Trifluoride	S. Kern* P. M. Raccah A. Tveten*	Accepted by J. Phys. Chem. Solids

* Author not at Lincoln Laboratory.

JA No.			
3620	Interband Magnetoreflection of α-Sn	S. H. Groves C. R. Pidgeon* A. W. Ewald* R. J. Wagner*	Accepted by J. Phys. Chem. Solids
3625	Report on the Symposium on Magnetic Semiconductors held in Yorktown Heights, N. Y., Nov. 1969	J. O. Dimmock	Accepted by Appl. Opt.
3628	Electronic Structure of Palladium	F. M. Mueller* A. J. Freeman* J. O. Dimmock A. M. Furdyna*	Accepted by Phys. Rev.
3650	Pressure-Induced Pyrochlore to Perovskite Transformations in the $Sr_{1-x}Pb_xRuO_3$ System	J. A. Kafalas J. M. Longo	Accepted by Materials Res. Bull.
MS-2677	Onset of Magnetism in Vanadium Oxides: ^{51}V NMR Studies of VO_x ($x = 0.86$ to 1.23)	W. W. Warren, Jr.* A. C. Gossard* M. D. Banus	Accepted by J. Appl. Phys.

Meeting Speeches†

MS No.			
2662	Two-Magnon Raman Scattering in $KNiF_3$	S. R. Chinn H. J. Zeiger J. R. O'Connor	15th Annual Conference on Magnetism and Magnetic Materials, Philadelphia, 18-21 November 1969
2663	Multiplet Structure in the Reflectance Spectrum of Europium Chalcogenides	J. O. Dimmock J. Hanus* J. Feinleib*	
2666	Magnetic and Optical Properties of the High and Low Pressure Forms of $CsCoF_3$	J. M. Longo J. A. Kafalas J. R. O'Connor J. B. Goodenough	
2668	Magnetic Ordering Effects in the Reflectance of EuS, EuSe and EuTe	W. J. Scouler J. Feinleib J. O. Dimmock T. B. Reed C. R. Pidgeon*	
2670	Localized Vs Band Magnetic Semiconductors	T. A. Kaplan R. A. Bari	
2679	Specific Heat of EuO	A. J. Henderson, Jr.* G. R. Brown* T. B. Reed H. Meyer*	

* Author not at Lincoln Laboratory.

† Titles of Meeting Speeches are listed for information only. No copies are available for distribution.

MS No.			
2703	Infrared Pumping of Microwave Lines of OH, H_2O, and H_2CO near IR Stars and Shockwaves	M. M. Litvak	131st Meeting of American Astronomical Society, New York, 8-11 December 1969
2723	Laser Raman Spectroscopy	A. Mooradian	Seminar, Stevens Institute of Technology, Hoboken, 3 December 1969
2723-A	Laser Raman Spectroscopy	A. Mooradian	Seminar, RCA, Princeton, 4 December 1969
2723-B	Laser Raman Spectroscopy	A. Mooradian	Seminar, University of Pennsylvania, 16 December 1969
2723-C	Raman Spectroscopy of Semiconductors and Its Applications	A. Mooradian	Topics in Quantum Electronics, University of California, Berkeley, 2 February 1970
2723-D	Laser Raman Spectroscopy	A. Mooradian	Seminar, University of Southern California, 3 February 1970
2723-E	Laser Raman Spectroscopy	A. Mooradian	Seminar, University of California, Irvine, 4 February 1970
2723-F	Laser Raman Spectroscopy	A. Mooradian	Seminar, California Institute of Technology, 3 February 1970
2731	Magneto-Optical Study of the Band Structure of BiSb Alloys	J. G. Mavroides	Seminar, Boston College, 3 December 1969
2734	OH and H_2O Masers in Infrared Stars	M. M. Litvak	Informal Seminar, Harvard College Observatory, 13 November 1969
2746	A New Variational Approach to the Question of Localized Vs Itinerant Electron Models	T. A. Kaplan	Physics Colloquium, University of Massachusetts, 12 December 1969
2748	Thermal Brillouin Scattering in Solids	A. S. Pine	Seminar, M. I. T., 21 November 1969
2762A	Anomalous Properties of the Vanadium Oxides	J. B. Goodenough	Annual Meeting of American Physical Society, Chicago, 26-28 January 1970
2778	N-P Junction Photodetector in InSb Fabricated by Proton Bombardment	A. G. Foyt W. T. Lindley J. P. Donnelly	IRIS Detector Specialty Group, Santa Barbara, 12-13 February 1970
2783	Two-Magnon Raman Scattering from Magnetic Insulators	S. R. Chinn	Physics Seminar, Bell Telephone Laboratories, Murray Hill, New Jersey, 15 January 1970

Division 8

MS No.			
2815	Remarks on the Mott Transition	T. A. Kaplan R. A. Bari	International Symposium on Atomic, Molecular, and Solid State Theory and Quantum Biology, Sanibel Island, Florida, 19-24 January 1970
2816	Spin Waves in the Alkali Metals	A. R. Wilson	Physics Seminar, Lowell Technological Institute, Lowell, Massachusetts, 14 January 1970
2824	Precision X-ray Scattering Measurements of Charge Density Distribution in Solids	P. M. Raccah	International Symposium of the Winter Institute, Sanibel Island, Florida, 23 January 1970

SOLID STATE
DIVISION 8

I. SOLID STATE DEVICE RESEARCH

Single-mode CW laser emission has been obtained at 12°K from a $Pb_{0.685}Sn_{0.315}Te$ diode at 31.8 μ. This is the longest wavelength semiconductor laser emission observed to date in the absence of a magnetic field. In addition, $Pb_{1-x}Sn_xTe$ diode lasers have been fabricated with threshold current densities as low as $20 A/cm^2$. To our knowledge, this is the lowest value ever observed for a semiconductor laser.

In continuing the study of the materials and electrical properties of $Pb_{1-x}Sn_xTe$ alloys, we have determined the Hall coefficient and electrical resistivity at 4.2°K of several samples with x up to 0.3. Mobilities as high as $5.4 \times 10^5 cm^2/V\text{-sec}$ have been observed for x = 0.2 with an n-type carrier concentration of $1.8 \times 10^{17} cm^{-3}$. Although the mobilities remain high in the alloy system, there is a trend toward lower values at higher Sn content.

$Pb_{1-x}Sn_xTe$ diode lasers have also been fabricated using evaporated Schottky barrier metal contacts instead of conventional p-n junctions. Metals such as Pb, In, Zn, and Sn with small work functions produce a narrow n-type degenerate inverted layer on the surface of p-type samples. When the diodes are forward-biased, electrons are injected from the inverted layer into the bulk. Low threshold diode lasers have been fabricated in this fashion from p-type PbTe with emission at 6.4 μ and from $Pb_{0.8}Sn_{0.2}Te$ with emission at 15 μ. Barriers have been observed on very narrow gap alloys of $Pb_{1-x}Sn_xTe$, and work is continuing to determine the maximum laser wavelength which can be obtained.

The amplification of 2.3-GHz acoustic waves in GaAs at room temperature has been observed using Brillouin scattering techniques. Amplification occurs through the piezoelectric interaction between the shear acoustic waves and electrons drifting under the application of an external electric field. The observed gain of 0.16 dB/volt is in good agreement with theoretical predictions.

The temperature and impurity concentration dependence of the electron mobility in high-purity GaAs has been determined. Adjustment of the conduction band deformation potential to 7.0 eV results in excellent agreement between experiment and a theory combining polar optical phonon, piezoeleetric acoustic phonon, deformation potential acoustic phonon, ionized impurity and neutral impurity scattering in the relaxation time approximation. Experimental 77°K mobilities of $210,000 cm^2/V\text{-sec}$ are very close to the calculated lattice limited mobility of $240,000 cm^2/V\text{-sec}$.

Room-temperature electrical resistivity of EuO is reported as a function of pressure up to 10 kbars. For the higher resistivity samples, the pressure coefficient corresponds very closely to the observed shift of the optical absorption edge with pressure. Both the temperature and pressure dependence of the electrical resistivity are explained in terms of a model in which electrons are distributed between a temperature and pressure sensitive conduction band and a localized stationary trap level.

II. MATERIALS RESEARCH

The phase diagram of the PbTe-PbSe pseudobinary system has been determined by thermal analysis. The relationship between the liquidus and solidus temperatures, both of which increase monotonically and sublinearly with increasing PbSe content, is given by the ideal form of the liquidus-solidus equation for binary alloy systems.

The composition stability limits of $(Pb_{1-y}Sn_y)_{1-x}Te_x$ alloys with y = 1.0, 0.9, and 0.8 have been determined by using x-ray diffraction analysis to measure the lattice parameters of annealed powder samples as a function of x, the atom fraction of Te. The metal-rich stability limit at 400°C is x = 0.5000 for all three values of y. The Te-rich limit at 350°C is x = 0.5070, 0.5058, and 0.5037 for y = 1.0, 0.9, and 0.8, respectively.

The pressure-composition phase diagram for the $Sr_{1-x}Pb_xRuO_3$ system at 1400°C has been determined by x-ray diffraction measurements on samples quenched to room temperature before releasing the pressure. The pyrochlore form of $PbRuO_3$ (x = 1), which is stable at atmospheric pressure, transforms to the perovskite form at 90 kbars. The pressure required to stabilize the perovskite form decreases with decreasing x, and for $0 < x < 0.3$ this form is the stable phase at atmospheric pressure.

III. PHYSICS OF SOLIDS

Ti_2O_3, a room-temperature semiconductor which undergoes a semiconductor-metal transition at 400°K, is being investigated by both optical reflectance and Raman scattering techniques. The reflectance measured in the photon energy range from 0.1 to 11.0 eV, only at room temperature so far, has been used in a Kramers-Kronig analysis to obtain the real and imaginary parts of the dielectric constant. The Raman spectrum, investigated from 1.7° to 800°K with an argon ion laser, indicates that all the Raman modes persist up to 800°K; this implies no change of crystal symmetry at the semiconductor-metal transition.

A study has been carried out of the optical properties of simple metals, including many-body effects. Results indicate that the optical properties can be calculated without an accurate determination of the many-body contributions, provided the energy band structure is known from experimental measurements.

A review of surface plasmon excitations in electron tunneling, low-energy electron diffraction (LEED), and photoemission indicates that the first technique, i.e., tunneling, provides a simple, sensitive probe for studying surface plasmon excitations. The latter two techniques suffer from complexity of the excitation mechanism; using the two-potential formula for scattering, a theory has been developed which gives quantitative support to the interpretation of structure in recent LEED and photoemission experiments carried out elsewhere.

An expression has been derived for the electrical conductivity of a crystal described by the single-band Hubbard model for the case of an energy bandwidth Δ that is narrow compared with the intra-atomic Coulomb repulsion U. For the half-filled band at zero temperature, the conductivity vanishes. For Li-doped NiO, only a negligibly small DC conductivity due to the $3d^8$-band hole-hopping is calculated. In another investigation of the Hubbard model, both in the exact treatment of the widely separated atomic limit ($U \to 0$) and in the thermal single-determinant variational approximation for small Δ/U, it is concluded that a phase transition at

$T_M \sim U/4k$, found by several different groups for small Δ/U using the thermal Hartree-Fock approximation, is entirely spurious.

The ground-state spin configuration in Cr_5S_6 has been calculated using the Heisenberg Hamiltonian and minimizing the energy by the generalized Luttinger-Tisza method. Parameter space maps have been constructed showing the various ground-state regions for particular sets of values for nearest-neighbor and next-nearest-neighbor interactions.

Two-magnon Raman scattering has been observed from the two-dimensional antiferromagnet K_2NiF_4. The experimental results at low temperatures are consistent with a theoretical Green's function calculation of the Raman spectrum and give a nearest-neighbor intraplanar constant $J = 77.0 \pm 2.0\,cm^{-1}$, which is in good agreement with that obtained from one-magnon neutron scattering.

Raman scattering from optical phonons in $Hg_xCd_{1-x}Te$ has been investigated for the range $0 \leqslant x \leqslant 1$ between 1.7° and 300°K. The alloys exhibit scattering of a type II system where both the LO and TO phonons characteristic of pure CdTe and HgTe are present with an intensity proportional to alloy composition.

Raman scattering from single-particle electron excitations gives a direct measure of the electron velocity distribution function. In GaAs, the previous equilibrium distribution results have now been extended to the nonequilibrium case by studying the scattering from carriers subjected to high pulsed electric fields, up to the Gunn threshold.

The phenomenon of acoustical activity of transverse waves, predicted theoretically by Portigal and Burstein, has for the first time been directly observed in α-quartz with microwave (~1 GHz) shear waves propagating close to the optic axis. The magnitude of the activity is in good agreement with that calculated from our recent Brillouin scattering determination of the linear wave vector splitting of the two transverse acoustic normal modes.

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13. ABSTRACT

This Quarterly Technical Summary covers the period from 1 November 1969 through 31 January 1970. It consolidates the reports of Division 2 (Data Systems), Division 4 (Radar), Division 5 (Optics), Division 7 (Engineering), and Division 8 (Solid State) on the General Research Program at Lincoln Laboratory.

14. KEY WORDS

data systems
digital computers
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air traffic control
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